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ABSTRACT

Identified are research, development, and organizational needs regarding sensory aids for the hearing impaired. Discussion of the present status of sensory aids focuses on acoustic and nonacoustic aids and points out that practical long-term utility has been extremely limited. Described are organizational and planning needs such as demographic surveys, public information programs and sensory-aid centers, and research and development needs, such as quantification of residual perceptual capacity and evaluation of existing sensory aids. (LS)

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Committee on the
Interplay of Engineering with
Biology and Medicine

Selected Research, Development and Organizational Needs To Aid the Hearing Impaired

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SELECTED RESEARCH, DEVELOPMENT, AND ORGANIZATIONAL NEEDS OF THE HEARING IMPAIRED

Subcommittee on Sensory Aids

COMMITTEE ON THE INTERPLAY OF ENGINEERING WITH BIOLOGY AND MEDICINE

NATIONAL ACADEMY OF ENGINEERING

Washington, D. C.

May 1973

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PREFACE

In June 1967, the National Academy of Engineering established the Committee on the Interplay of Engineering with Biology and Medicine under a contract with the National Institutes of Health. The broad purpose of the Committee is to delineate the ways in which engineering theory and practice can contribute to the solutions of problems in biology and medicine.

The Committee formed subcommittees to address some pertinent topics. The Subcommittee on Sensory Aids was formed in 1969 to stimulate, initiate, innovate, and correlate research into and development, evaluation, and deployment of sensory aids for the hearing and visually impaired. Through meetings, the pursuit of their own research, and their familiarity with other investigators and projects in the United States and abroad, the members of the Subcommittee have become aware of current sensory-aid needs, accomplishments, and opportunities.

The primary purpose of this report is to identify areas that warrant further research and development. Topics are described briefly and categorized as pertaining to either research or organizational and planning needs. The report is not intended to imply that none of these topics is receiving attention. Work in several subjects is underway at various places in this country and elsewhere.

This report is not a detailed review of the state of the art of sensory-aids for the hearing impaired, nor does it deal explicitly with the requirements for such aids and techniques. Those important subjects were covered in a specific Subcommittee conference on sensory training aids for the hearing impaired, attended by a select international group of

engineers, speech and auditory scientists, physicians, and educators. Other aspects of sensory-aid evaluation were covered in a similarly structured conference on the evaluation of mobility aids for the blind. Proceedings of both conferences are available from the National Academy of Engineering.*

The Subcommittee recognizes the urgent need for focusing and structuring national efforts in sensory-aid research, development, evaluation, and deployment. A report, "Sensory Aids for the Handicapped: A Plan for Effective Action," establishes the rationale of such efforts and the benefits, both economical and humane, to be derived from them. It also delineates alternative mechanisms to link research and social needs to stimulate the development and use of appropriate sensory-aids for the blind and deaf.

Although we hope that the contents of this report will receive the attention of those already involved in sensory-aid development and application, it is directed especially at the dynamic teacher and clinician whose experiences and ideas can contribute to the greater efficacy and adoption of sensory aids for the hearing impaired. Equally important, the report is intended to mirror needs and opportunities for those benefactors--both government and private--who may be seeking to identify worthwhile projects for application of their resources and who are responsible for organizing the nation's capacity to implement effective programs.

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*Proceedings of the Conference on Sensory Training Aids for the Hearing Impaired. H. Levitt and P. W. Nye (Ed.). National Academy of Engineering, Washington, D. C., 1971. Proceedings of the Conference on the Evaluation of Mobility Aids for the Blind. P. W. Nye (Ed.), National Academy of Engineering, Washington, D. C., 1971.

Finally, we hope to stimulate new concepts and encourage creative minds to enter this exciting arena. We offer to scientists and engineers seeking new applications for their talents a field that is both intellectually challenging and humanly rewarding.

Robert W. Mann, Chairman
Subcommittee on Sensory Aids

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INTRODUCTION

A coordinated program of research and development in the field of sensory aids is necessary if the potential of currently available knowledge for meeting the needs of the deaf is to be realized. This document itemizes research and development needs to outline the components of such a program and to stimulate the development of individual research proposals. The areas selected, in the collective judgment of the National Academy of Engineering's Subcommittee on Sensory Aids, would contribute most to such a coordinated program.

During the early stages of a coordinated program, broad questions must be addressed: What is needed? By whom? What gaps in our knowledge of the deaf must be filled? What are the fundamental perceptual, physiologic, and technical areas that require support? The few demographic studies that exist need considerable extension to answer these questions.

Hearing is strongly coupled to a human activity of immense importance -- speech. It is also the basic mechanism by which a normal child develops the essential tool for communication and abstract thought -- language. The deaf, therefore, require sensory aids not only to facilitate communication in general, as do the blind, but also to help specifically in the acquisition of language.

Modern technology provides a variety of sensory aids for the deaf. The operating principles are either to amplify sound as much as possible, using whatever residual hearing the deaf may have, or to detect some acoustic features and transform them into signals in other areas of the auditory spectrum or into other sensory modalities. However, although the essential technology for such devices is well established,

in general their merit has not been evaluated, and optimal methods for using them or for training users in their application are essentially unexplored.

The goal of our Subcommittee is to speed the development of devices and systems that are of direct and extensive utility to the hearing impaired. In the pages that follow, we first offer some general assessments of the present status of the field and then list 11 specific projects that warrant immediate attention. Principal stress is placed on determining the best means of using and deploying existing sensory aids, on methods of device and system evaluation, and on determining optimal methods of training. Although adequate hearing implies an ability to perceive a great variety of sounds, because of its overwhleming importance, speech is given great emphasis.

The 11 project descriptions are not intended to be exhaustive; rather, they are suggestive and are meant to stimulate further interest and exploration. A final summary provides short abstracts and classifies the listed projects into those of an organizational nature and those involving sensory-aid research and development. In neither section is any rank ordering of importance of the listed projects intended.

The references listed at the end of the report represent the best available statements on the state of the art and will lead the reader to the bulk of the literature on the various topics.

The Subcommittee invites comment and queries, addressed to:

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PRESENT STATUS

The acquisition of language and satisfactory communication by speech are two different, although related, activities. This bears on sensory aids for the deaf in the following way: A person who loses his hearing after learning to speak will retain his speech, despite a tendency for its quality to deteriorate. Also, a relatively mild hearing loss can be adequately overcome with conventional hearing aids that amplify the important acoustic energy of speech. Hence, those who become deaf after acquiring normal language and speech may need only special training in the use of an available and effective sensory aid. However, a child who is born with a hearing impairment or who loses a substantial portion of his hearing prelingually - i.e., before the age of about 2, will not autonomously learn to speak or to perceive speech. He will need assistance in the acquisition of language, as well as aids to facilitate the development of oral communication skills, both expressive and receptive. Very early diagnosis and treatment of such cases is vital.

Thus, the three classes of communication problems of deafness -- hearing, language, and speech -- necessitate different kinds of sensory aids. One, such as the conventional hearing aid, is designed to transmit and amplify acoustic signals from the environment. The second is designed to facilitate the ability to acquire language and includes devices to present information in a programed fashion, using visual and/or tactile clues. The third provides a medium directed toward the development of speech, the improvement of speech intelligibility, and the remedy of speech errors.

What approaches to sensory aids are available? A most attractive one, the acoustic approach, takes advantage of whatever hearing a deaf person may possess. This is not as impractical as it might sound; few people are totally deaf. The great majority of the hearing impaired have some

residual hearing that, at least to some degree, is potentially usable with auditory training and with a properly chosen sensory aid. In another approach, the nonacoustic, the acoustic signal is transformed and presented in another sensory modality. The two types of sensory aids associated with these approaches are discussed briefly below.

Acoustic Aids

Complete absence of auditory response among the deaf population is very rare. As a consequence, the effort to take advantage of residual hearing has led to the development of two types of sensory aids in the acoustic class.

The more common one involves nothing more than sound amplification as provided by conventional hearing aids, the acoustic energy being delivered either by air-conduction or by bone-conduction receivers. The rationale for this type of aid has merit: Some auditory information is better than none, and the aids are readily available. For many profoundly deaf, the auditory information provided will include minimal characteristics of vowels, intonation, and rhythm, as well as valuable orientation clues. As noted above, the acoustic amplification provided by these aids is of great benefit to those with less severe hearing impairment.

Some information on the optimal acoustic design of sound-amplifying aids is available.[1,2] However, further extensive research is required on optimal frequency responses, on the use of automatic gain control and output limiting, on custom fitting, on the use of binaural aids, on portability, and on the design of group aids for use in classrooms of hearing-impaired children. The acoustics of many classrooms are unsuitable for making the best use of hearing aids; further experiments on and dissemination of information about optimal classroom acoustics are needed.

An important additional consideration in the design of such aids is that today they are often placed on babies in their first few months of life. It is not sufficient

to design instruments solely for adult consumers. In designing aids for infants, attention must be given to reliability, simplicity, size and weight of the aid, earmold design for young and growing ears, and the fact that an infant wearer is not capable of compensating for imperfect performance.

The second type of acoustic sensory aid transforms speech signals. Broadly speaking, there are two kinds of transformational aids. In one, the speech-significant acoustic spectrum is compressed to a range more nearly comparable with the residual-hearing range. For example, signals in the speech-frequency bandwidth, 100-3,500 Hz, can be compressed and shifted downward to reside within 50-1,750 Hz. Features of spectral shape may be acoustically preserved after the transformation. Empirically, tests are made to determine whether the resulting acoustic signal can be assimilated and its information content taught. There is no substantial evidence yet that this spectral compression approach is effective. The other kind of acoustic transformational aid potentially has many forms. An ultimate form would convert any natural acoustic segment, presumably phonetically related, into an optimal acoustic replacement. Production of such a device is remote. One device under test transposes the high-frequency energy of fricatives to low-frequency energy by a special countdown procedure for zero crossings of the acoustic waveform.[3] The natural speech spectrum is otherwise unchanged.

Nonacoustic Aids

Nonacoustic sensory aids are designed to use vision and/or the tactile sense as the avenue of communication. Devices using touch convert sound into mechanical vibration or use electrodermal stimulation.[4] In one approach, a vibrator is driven by the filtered speech signal.[5,6] In another, the speech signal is analyzed in real time and divided into frequency bands; the average amplitude of each band is used to modulate simultaneously an array of stimulators applied to skin areas (e.g., each of the fingertips).[7-9]

Current results indicate that tactile signals may be useful as a supplement to speech reading (i.e., lipreading)[10] or as an aid in speech training.[11] It must be recognized that for the deaf person speech reading is usually the primary source of input; any device that will improve the reliability of this mode of communication is much to be desired. Tactile clues that augment speech reading, particularly with regard to the timing of spoken communication, would appear to have valuable potential for exploration.

Visual display of the speech signal has taken many forms. The most elaborate has been the Visible Speech Translator,[12-14] which offers a real-time representation of the speech spectrum on a cathode-ray tube. Specialized displays of frication, nasality, intonation, vocal intensity, vowels, and other speech characteristics are also available.[15, 16] The displays may appear on cathode-ray tubes, meters, banks of lights, eyeglasses, and even some ingeniously designed toys intended to hold a young child's attention during training periods.

The applicability of many of these devices either to speech training or to communication between and with deaf people is discussed in recent surveys.[17-20] With these devices, some modest successes have been reported in speech instruction.[21]

Another class of devices would bypass the peripheral receptors in the body. Electrodes implanted in the auditory nerve or in the brain would electrically stimulate the nervous system. Research has been limited, and the outlook for practical implementation soon is not promising.[22, 23]

Finally, there is a large class of devices that do not operate on the acoustic speech signal. A number of forms are being tested or are in use, especially those transmitting manual languages and writing (classic sensory aids). Telephone communication is feasible through the use of alphanumeric pushbutton signaling, picture transmission, and teletypewriter services.[24]

Other Types of Aids

Some aids (perhaps not properly termed "sensory") that at least partially automate training are potentially valuable. A hearing person is usually the only available interpreter linking a normal speaker with a deaf person. The hearing person also provides the needed feedback to a deaf person learning to speak. Automated teaching methods applied to auditory training are being tested,[25] and automated teaching of restricted features of speech is possible now. Through the use of digital computers, more complicated recognition and training algorithms are feasible.[26, 27]

Methods of Evaluation

Evaluation of sensory aids for the hearing impaired is difficult; the territory is virtually uncharted. Conventional intelligibility tests adopted from telephone engineering apply to only a few components of the communication problems of the deaf. Such tests are widely recognized as unsatisfactory, but there has been little effective development of supplements. Effective two-way communication requires much more than good one-way articulation or intelligibility scores. Of even greater concern is that the evaluation may concentrate on too narrow a problem. The deaf person is faced with a multitude of problems, and it is possible for a device to be helpful in one and detrimental in others. Extensive research in evaluation is required.

Summary Assessment

Although many sensory aids are ingeniously designed and earnestly applied, practical long-term utility has been extremely limited. This is primarily because most design has been ad hoc, many of the perceptual requirements remain unknown, and effective training and evaluation techniques are embryonic. Teachers and therapists working

with the deaf frequently have not been convinced of the value of devices, even when available, and thus have not supported their use. Furthermore, we have only a rudimentary knowledge of the basic processes of speech and language, and understanding of what is truly essential for effective communication is still lacking.

DESCRIPTIONS OF SELECTED NEEDS

Organizational and Planning Needs

Demographic Surveys: The need for aids to train and assist the hearing impaired to communicate effectively has long been recognized. The hearing impaired population is highly heterogeneous, with diverse needs; for example, the needs of a congenitally deaf child are very different from those of an adult with gradually deteriorating hearing. Furthermore, the type of sensory aid best suited for a particular child may depend heavily on such factors as etiology, degree of hearing impairment, and age of onset of hearing impairment. Much valuable information can be extracted from currently available Public Health Service census data[28] and other surveys[29, 30] on the incidence of deafness in the United States, but more demographic information is required to define and categorize sensory-aid needs and to establish priorities for research on devices and systems to meet these needs.

Public Information Programs: Deafness is not a conspicuous handicap, yet the effects of a severe hearing impairment are overwhelming, particularly to a prelingually deaf child. The general public appears to be largely unaware of the debilitating effects of profound deafness, presumably because their exposure to hearing impaired persons is limited primarily to those with relatively minor hearing impairments. The situation is not improved by the many tasteless jokes in our society that involve hard-of-hearing persons and that belie the seriousness of a severe hearing handicap. Much needs to be done to educate the public about the less obvious but more severe implications of deafness, the extent to which aids and special training can assist the hearing impaired, and the importance of subsidizing, through both public and private funding, research and services for the hearing impaired.

Multidisciplinary Interaction: Research in sensory aids for the hearing impaired encompasses a number of disciplines, including engineering, medicine, psychology, physiology, speech sciences, linguistics, audiology, and education. Because of the disproportionately large range of disciplines involved, there is an unfortunate lack of contact among workers in different fields. Methods of enhancing contact among educators, researchers, and engineers include:

(1) organizing multidisciplinary conferences and workshops on a regular basis;

(2) providing teachers with tutorial material and seminars in speech, hearing, and linguistics, including exposure to the latest research findings; and

(3) establishing fellowships for researchers for full-time work in teaching and clinical environments.

Sensory-Aid Centers: To develop sensory aids for the hearing impaired, it is necessary to have research centers with the appropriate facilities, personnel, and sense of mission to provide a well-organized, coordinated attack on the problem. Because of the broadly multidisciplinary nature of sensory-aid research and development, the efforts of several workers in concert are necessary, thereby requiring a fairly large laboratory or center, regional or national. There is a volunteer corps of researchers whose choices of subjects of investigation are constrained by limited research facilities, lack of day-to-day contact with others working in related subjects, and meager financial support. As a result, the current research effort is uncoordinated and tends to be overly concentrated in peripheral subjects that provide small, manageable research projects for individual researchers. A major attack on the

fundamental underlying problems is unlikely without some pooling of resources and talent in a larger framework. (Suggested approaches toward some form of national center, laboratory, or foundation are found in the National Academy of Engineering publication, "Sensory Aids for the Handicapped: A Plan for Effective Action.")

Wider Use of Existing Sensory Aids: A number of new sensory aids and associated techniques have been found to work well in objective evaluations, and these should be used as widely as possible to obtain maximal benefits. Three projects that would have valuable and immediate benefits at a moderate cost are:

(1) the establishment of a nationwide program for screening all high-risk babies for evidence of hearing impairment and other sensory defects;

(2) the fitting of hearing aids to all infants as soon as hearing impairment is diagnosed; and

(3) the provision of teletypewriters at nominal cost to all hearing impaired persons who need and can use them.

Research and Development Needs

Fundamental Research on Speech and Language Acquisition in Hearing Impaired Children: The science of psycholinguistics is in its infancy; little is known about speech and language development in normal children and even less in the case of deaf children. Nevertheless, crucial decisions on the education of deaf children are continually being made. A key assumption underlying many educational programs is that language acquisition in deaf children follows essentially the

same pattern as in normal children, except that the time scale is considerably extended. Recent developments in psycholinguistics provide useful guidelines by which language development in deaf children may be measured.[31-35] It is important to establish whether language acquisition in the deaf follows the same hierarchy of development (albeit on an extended scale) as in normal children, or whether new language forms are developed in a different manner.

The orientation of this research effort should be concerned not only with the process of speech and language acquisition and with how it is affected by hearing impairment, but also with the determination of the remedial needs and what can be achieved. The phrase "speech and language" is used here in the belief that the two are intimately intertwined and that both oral and written forms of language should be investigated.

Quantification of Residual Perceptual

Capacity: The intellectual development of a deaf child depends directly on all his perceptual abilities, including residual hearing capacity. Methods of quantifying visual and tactile information-handling capacity in the hearing impaired child need to be investigated. Because hearing impaired children frequently also suffer from other sensory impairments, that possibility must always be considered.

The specification of hearing impairment only in terms of an audiogram is clearly inadequate, and more appropriate methods are needed. Some research on the relation between residual hearing and speech perception is in progress,[36, 37] but much more is required.

The future development of sensory aids depends heavily on the extent to which residual hearing and other perceptual modalities can be used in the transfer of information. The extent is crucially age-dependent and this should be considered in investigating intermodality transfer.

The search for practical substitutes for speech should be pursued. A promising approach that merits immediate consideration is the presentation of key articulatory information (e.g., place, manner, voicing cues) visually or tactually as an aid to speech-reading.[38-40] The problems of automatically extracting such information from the acoustic speech signal are not trivial and need to be studied.[41]

Improvement of Diagnostic Techniques: Closely linked to the problem of quantifying residual hearing capacity is that of obtaining an accurate diagnosis of hearing disorders. This is a constantly evolving process, but at present the emphasis should be on developing reliable audiometric procedures for very young children and children with behavioral problems or concomitant impairments. Also required is the development of tests of communication ability that realistically predict a hearing impaired person's performance in real-life situations (e.g., speech perception under noisy or reverberant conditions). Methods of establishing measures of speech reception at the feature, syllable, sentence, and paragraph levels have been suggested,[42] and these techniques should be investigated.

Development of Evaluation Procedures: The evaluation of sensory aids is neither simple nor trivial. Traditionally, objective evaluation procedures have compared a new device or technique with conventional devices or techniques. Unfortunately, "conventional" systems are not always well defined or evaluated themselves. They may encompass a wide variety of techniques of varied effectiveness.

A more serious problem lies in defining the scope of the evaluation. A well-designed evaluation that is narrow in scope may show a device to be effective for a specific task when, in fact, the impact of the device on a broader scale may be less than desirable. A simple example is a device that helps a deaf child produce individual speech sounds correctly while detracting from the child's overall fluency by overemphasizing individual sounds.

In many cases, evaluation needs to take place in a school or clinic, in which many variables are beyond the experimenter's control. Practical evaluation procedures need to be developed that are objective, reliable, and simple to use, despite the diversity of uncontrolled variables in schoolrooms, clinics, etc.

Evaluation of Existing Sensory Aids: A number of sensory aids [15, 16] that have been developed appear potentially useful, but have not been evaluated in any depth. Closely linked to the development of new devices is the development of specialized training procedures for use with these aids. Systematic, objective evaluation of existing sensory aids and training procedures is urgently needed. Apart from determining whether a new device or technique improves communication skills, it is important to know in quantitative terms the strengths and weaknesses of existing aids, so that sensory aids of improved design can be developed.

Of the various sensory aids for the deaf that have been developed over the years, aids for speech training appear to be the most promising for the immediate future. Evaluation of such aids should take into account rate of progress, transfer of skills, and retention of skills after termination of specialized training.

Efficiency of evaluation is very important, and the use of sequential testing procedures should be considered as a means of terminating experiments as soon as significant improvement (or lack of improvement) is established. In the evaluation of speech training aids, one should consider the development of semiautomatic or computer-controlled systems that permit several users to receive concentrated training simultaneously from a single teacher.

Improvement of Conventional Hearing Aids: Considerable research is still needed on finding the optimal electro-acoustic characteristics of conventional hearing aids and on ways of fitting hearing impaired persons with aids that best meet their individual requirements. To do this, hearing impairments first have to be classified according to their origin and physiologic nature and to the social, educational, and communicative situations in which they offer serious handicaps. The hearing-aid requirements of each of these groups then will have to be determined experimentally, and clinical procedures developed for fitting individuals with the most suitable aids. For a detailed review of work in this area, see Ling.[43]

A number of design improvements that could be introduced into commercial aids without significant research include smoother frequency-response curves, reduced nonlinear distortion (especially when battery power begins to drop), and practical directional microphones. The special problems of hearing aids for children - including physical robustness, small size, improved earmold design for small and growing ears, and some means of monitoring externally (e.g., by the teacher) whether or not the aid is working -- should be considered.

Optimal specifications need to be developed for wearable hearing aids and for group hearing aids (wireless or loop types). The latter require consideration of frequency response, permissible degrees of distortion, and relative volumes of the teacher's voice, the child's own voice, and other children's voices.

For more detailed information on research needs for hearing aids, see Directions for Research. . . .[44]

Summary

This report has identified eleven kinds of need grouped into two major categories.

Organizational and Planning Needs:

1. Demographic Surveys: Collection of data through demographic surveys of the hearing impaired population to help determine the need for special training and the kinds of sensory aids that would most benefit that population.

2. Public-Information Programs: Stimulation of public awareness of the need for and the potential of research for providing effective aids, a primary goal being the development of a favorable climate for obtaining funds (both public and private) to support research and services for the hearing impaired.

3. Multidisciplinary Interaction: Development of mechanisms to overcome the severe lack of communication among researchers, educators, and others and to enhance mutual exposure and interaction among workers in different specialities.

4. Sensory-Aid Centers: Establishment of national centers for sensory aids to implement programs in research, development, evaluation, and deployment.

5. Wider Use of Existing Sensory Aids: The widest deployment possible of the several existing sensory aids that have shown a fair degree of success in objective evaluations.

Research and Development Needs:

6. Fundamental Research on Speech and Language Acquisition in Hearing Impaired Children: Concentrated research on the nature of language acquisition in hearing impaired and normal children not only to encompass the basic process of language acquisition and its link to hearing, but also to determine the major remedial needs and possibilities. Investigations should keep in close touch with work carried on in the practical training of deaf children, where interesting observations are often made that call for sound research to establish their validity.

7. Quantification of Residual Perceptual Capacity: Coordinated research to measure residual perceptual capacities of the hearing impaired, including measurements of visual and tactile information-handling capacity of deaf persons and the quantification of commonly occurring concomitant sensory impairments.

8. Improvement of Diagnostic Techniques: Improvement of diagnostic techniques, particularly with respect to isolating the sources of failure in communication, but with emphasis also on the development of reliable audiometric procedures for very young children and on developing tests of communication ability that can more realistically predict performance in real-life situations (e.g., speech reception by a hearing impaired listener under noisy or reverberant conditions). New techniques should be explored.

9. Development of Evaluation Procedures: Development of practical and objective evaluation procedures that take into account the total impact of the evaluated device or technique on the functioning

of the user, including simple and reliable procedures that can be conveniently administered with robust equipment in schools and clinics.

10. Evaluation of Existing Sensory Aids: Systematic, objective evaluation of existing sensory aids and training procedures to determine which new devices and techniques improve communication skills and to know in more quantitative terms the strengths and weaknesses of existing aids, so that ever better aids can be developed.

11. Improvement of Conventional Hearing Aids: Improvement of the design, fitting, and evaluation of conventional hearing aids (the single most important sensory aid for the hearing impaired), including the determination of optimal frequency responses and permissible degrees of distortion, as well as the development of practical directional microphones and high-power, low-cost aids with smooth frequency-response curves. This should, and probably could, involve both private and public agencies.

EPILOGUE

To those already involved in sensory-aid research and development, the Subcommittee's assessment of urgent needs can serve as a checklist against which other views and proposals can be weighed. For those searching for new opportunities, it is hoped that this brief discussion has provided a first step in the process of identifying challenges and finding ways to meet them. Except for an occasional hint of potentially fruitful avenues that merit consideration, the creation of definitive projects in any of the subjects listed is left to those who will carry them out. To aid in this endeavor, the following pages list basic source documents that define more completely the problems in this field, describe the current state of the art, and indicate places and people currently active in the field. These source documents abound in reference citations that cover the relevant literature.

CITED REFERENCES

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